Nuclear physics at ISOL@MYRRHA

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MYRRHA

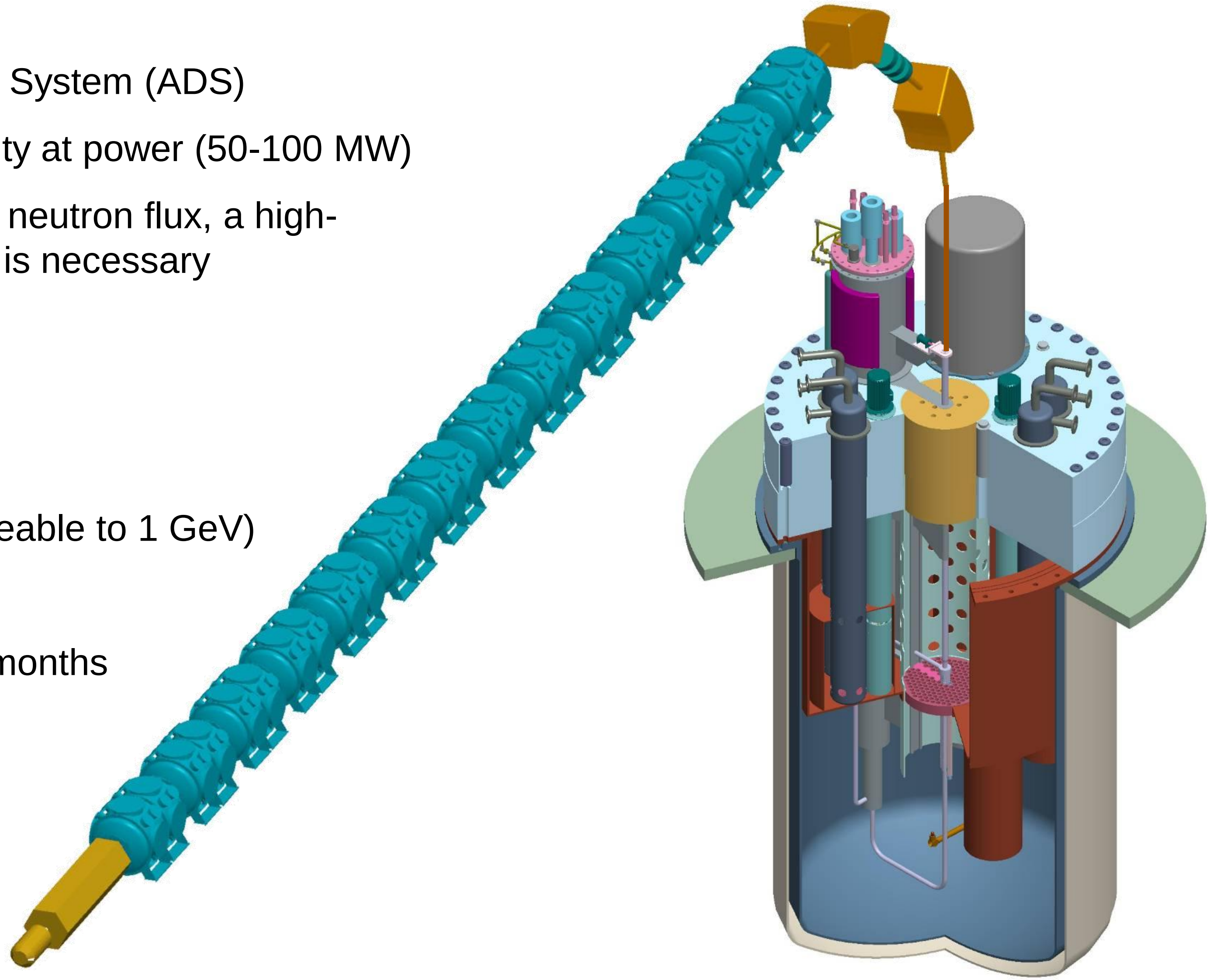
An Accelerator-Driven System (ADS)

A first-step demo facility at power (50-100 MW)

To obtain the required neutron flux, a high-intensity proton driver is necessary

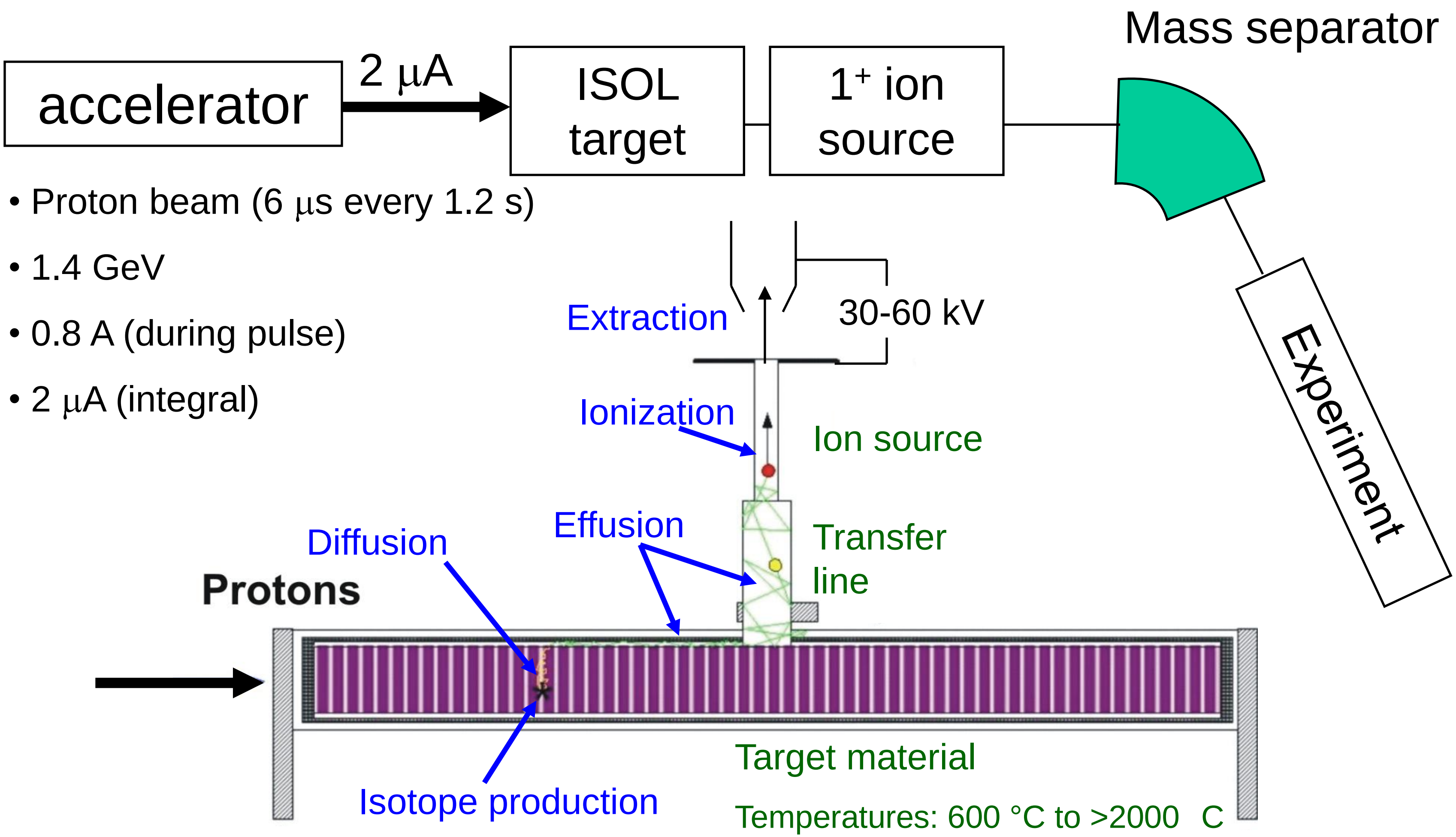
PROTON DRIVER

- E=600 MeV (upgradeable to 1 GeV)
- I=2.5 mA (CW)
- <5 trips (>1s) per 3 months
  =Stable and high reliability



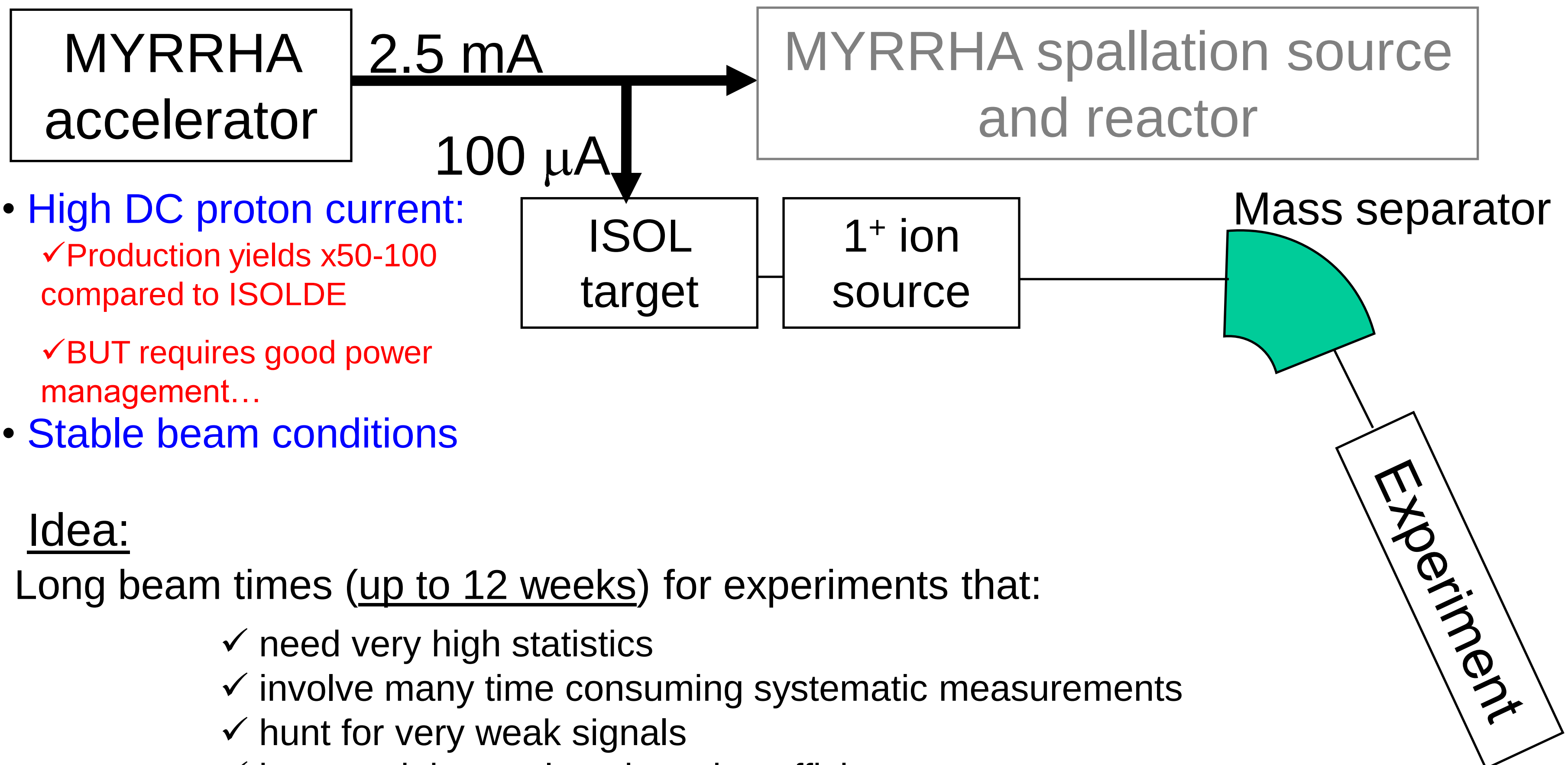
Isotope Separation On-Line (ISOL)

Typical example: ISOLDE



- Proton beam (6 μs every 1.2 s)
- 1.4 GeV
- 0.8 A (during pulse)
- 2 μA (integral)

ISOL@MYRRHA



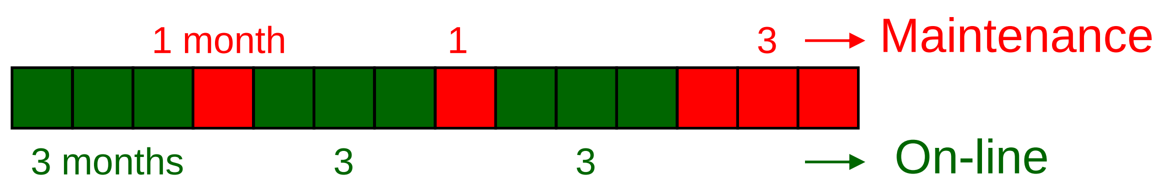
- High DC proton current:
  - ✓Production yields x50-100 compared to ISOLDE
  - ✓BUT requires good power management…
- Stable beam conditions

Idea:

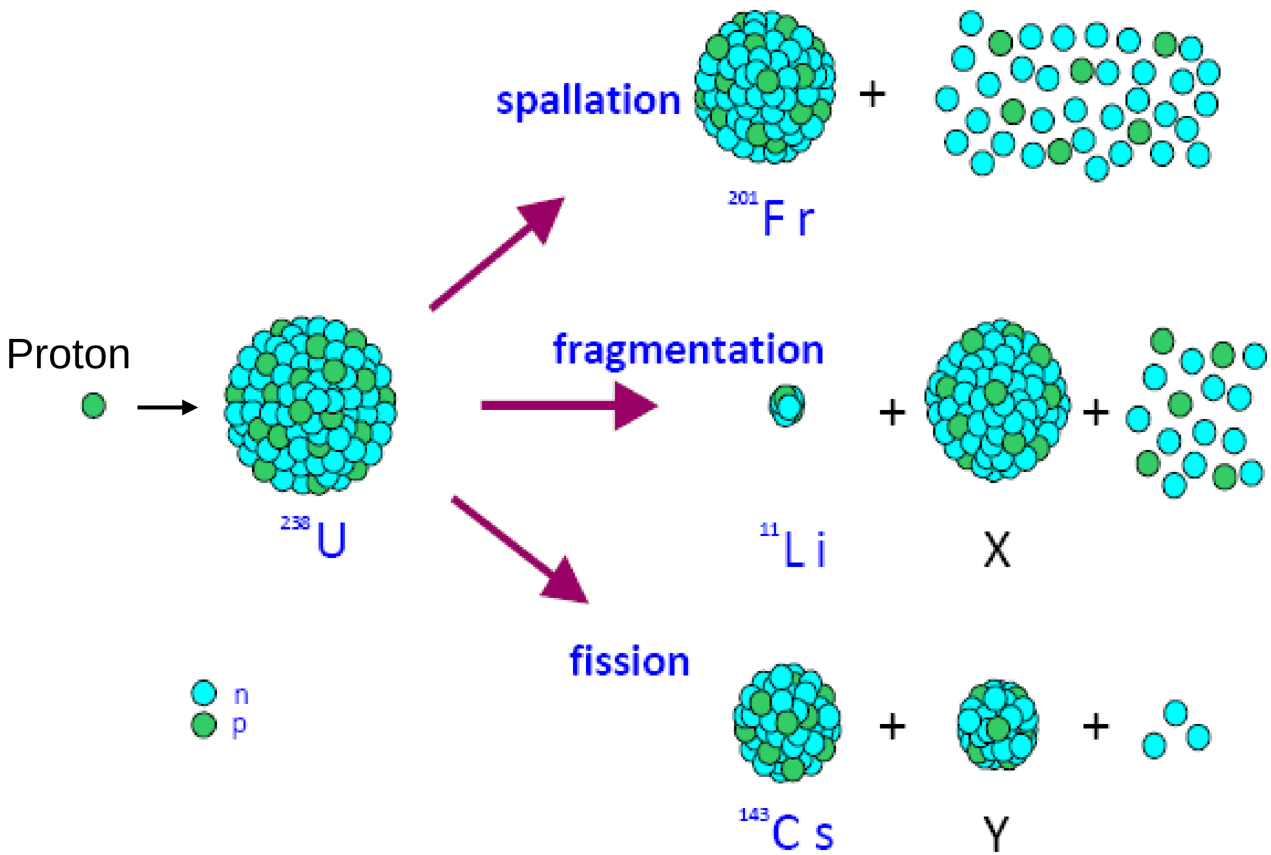
Long beam times (up to 12 weeks) for experiments that:

✓ need very high statistics
✓ involve many time consuming systematic measurements
✓ hunt for very weak signals
✓ have an inherent low-detection efficiency

The MYRRHA cycle:



Nuclear reactions



Roughly speaking

Z_{target}-15<Z<Z_{target} on neutron-deficient side

slightly centered on neutron-rich side

on neutron-rich side

Protons on ^{238}U

<u>Use ruggedized targets like</u>:

SiC/C (Z=14)

TiC/C (Z=22)

Nb (Z=41)

La (Z=57)

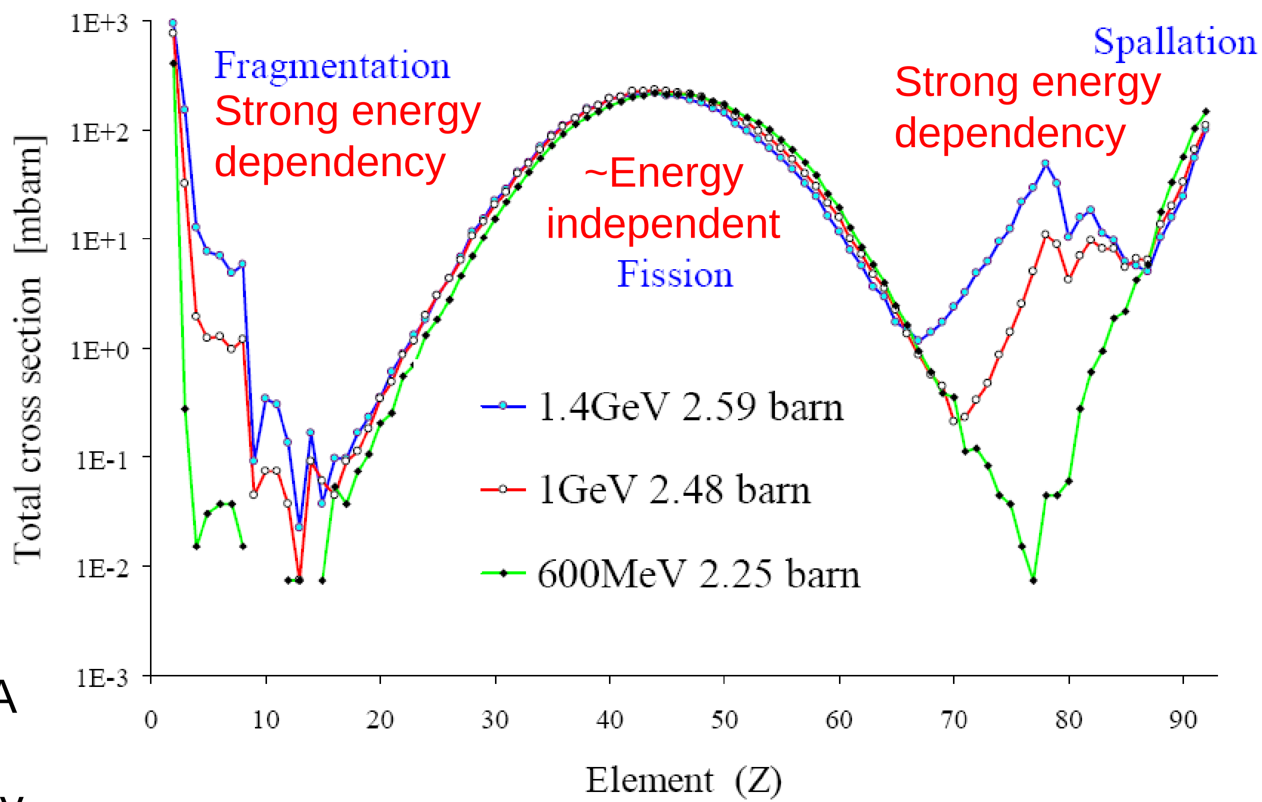
Ta (Z=73)

UC/C (Z=92)

For most of the neutron-rich nuclei

<u>State-of-the-art ruggedized targets</u>:

- TRIUMF, Vancouver (Canada)
  - ✓ 500 MeV, 100 μA proton beam
- EURISOL design study
  - ✓ 1 GeV, 100 μA proton beam



Ruggedized targets

TRIUMF targets

Achievements so far at TRIUMF

SiC/C (Z=14) : up to 37.5 kW beam

TiC/C (Z=22) : up to 35 kW beam

Nb (Z=41) : up to 20 kW beam

Ta (Z=73) : up to 37.5 kW beam

(http://www.triumf.info/facility/research_fac/yield.php)

Current developments at TRIUMF

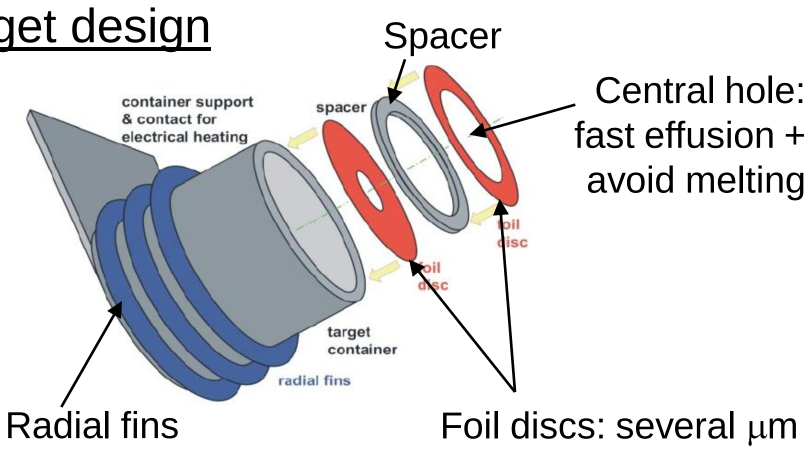
Rotating beam on annular targets: 50-100 kW is expected to be feasible

LaC/C (representative for UC/C) target tests

EURISOL metal-target design

R. Wilfinger et al., Eur. Phys. J. Special Topics **150**, 379 (2007)

- Rotating beam
- No uniform heating: axial target thickness is graded according to beam power deposition



Selective and sustainable ion sources

1. Surface ion source

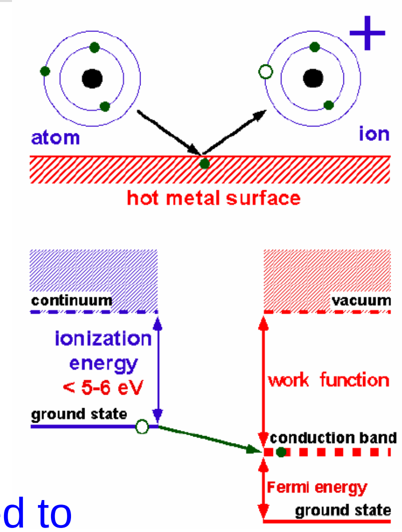
High work function materials:

Ta (4.19 eV)

W (4.53 eV)

Re (5.1 eV)

Alkali elements



2. Cold transfer tube coupled to radiation-hard Electron Cyclotron Resonance (ECR) ion source

ECR: not selective (ionizes all elements)

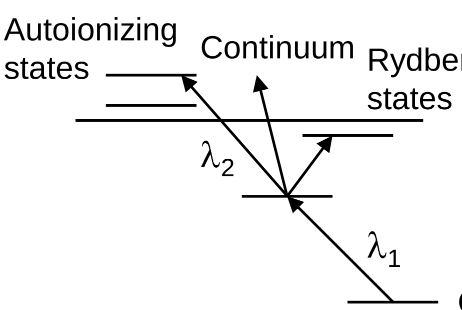
Cold transfer: trap less volatile isobaric contaminants

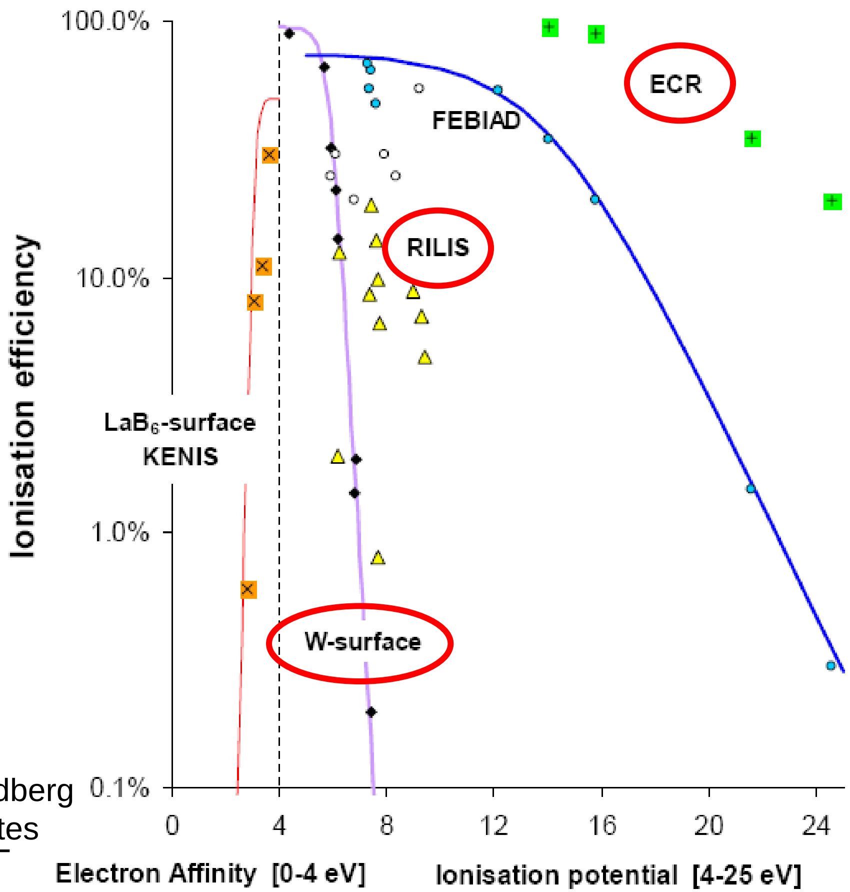
Noble gases (+ C, N, O)

3. Resonant Laser Ionization

Ionization efficiency: ~10%

Ionization scheme for ~80% of the elements





ISOL@MYRRHA: a unique RIB facility

- Stable 100-μA beam on ruggedized targets (UC/C no problem on nuclear site) for intense radioactive ion beams is feasible:

  ~ x50-100 compared to ISOLDE

- Selective and efficient ion sources for pure radioactive ion beams
- Very long beam times (with a stable proton driver)
- Nuclear education with hands-on experience

Physics cases:

- Fundamental nuclear structure (small β-decay branches, scanning measurements)
- Fundamental interactions (high-precision measurements)
- Solid-state physics (e.g., ^{8}Li β-NMR for many samples, much beam time)

ISOL@MYRRHA → complementary to other facilities:

HIE-ISOLDE, CERN
SPIRAL2, GANIL
SPES, Legnaro
EURISOL

Case I: Fundamental interactions

Nuclei of interest

- nuclei at or close to the **N = Z line**
  - nuclei with **$0^+ \rightarrow 0^+$ transitions**
  - **T = 1/2 mirror nuclei** (N = Z-1 → N = Z+1; e.g. $^{21}Na \rightarrow ^{21}Ne$)
- nuclei with **fast** (small log*ft*) and pure **Gamow-Teller transitions**

Possible subjects

1. ***$Ft^{0^+ \rightarrow 0^+}$***
   - **Conserved vector current hypothesis**
   - **unitarity of Cabbibo Kobayashi Maskawa quark mixing matrix**
   - **right-handed currents**
   - **scalar currents**
2. **searches for exotic weak currents**
   - **scalar currents**
   - **tensor currents**
3. **symmetry tests**
   - **parity**
   - **time reversal**

0^+->0^+ super-allowed Fermi transitions

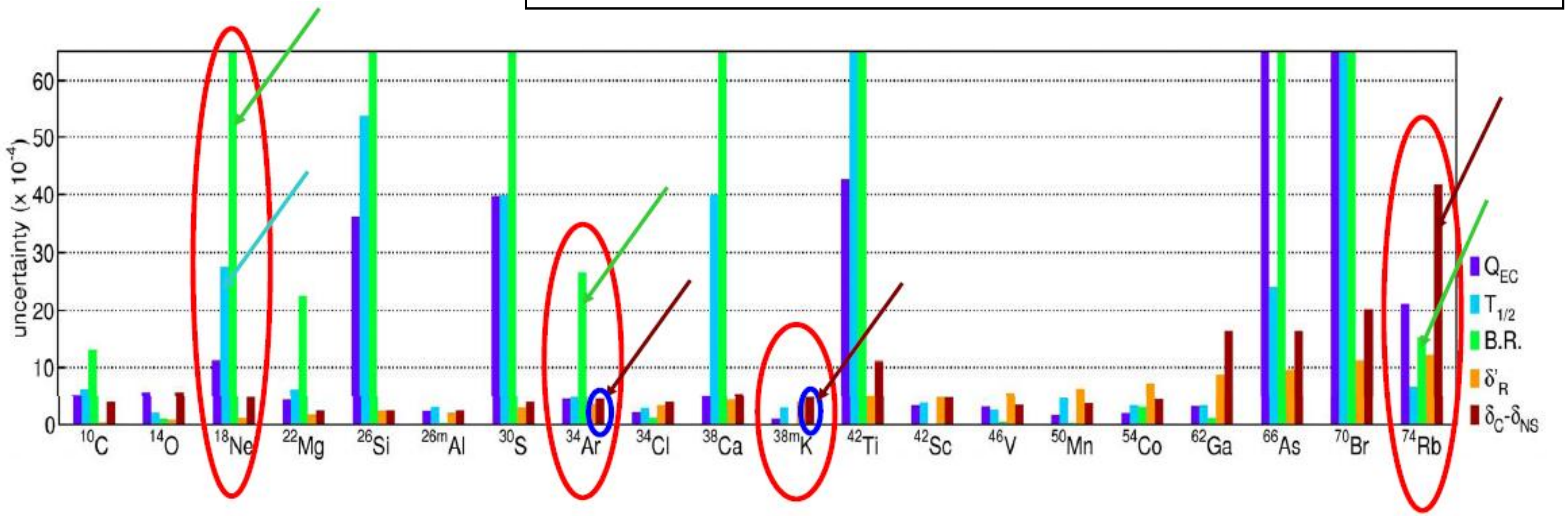
Error budget, required precision, and opportunities for ISOL@MYRRHA (arrows)

$$Ft = ft\,(1+\delta_R)(1+\delta_{NS}-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R^V)} = 3074.4(12)s$$

- **overall precision: 4 * 10^{-4}**

⇒ **single measurements of $T_{1/2}$ and BR : < 10^{-3}**

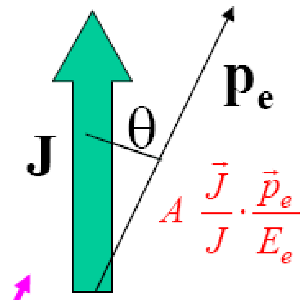
- **theoretical corrections: $\delta_{Coulomb}$, $\delta'_{Radiative}$ ~ 1% → < 10%**



Options: - improve quantities indicated by green & blue arrows
- if CVC accepted → Ft-measurements test δ_c - δ_{NS} from theoretical models
- go for factor ~10 higher precision in Ft than available now for the 4 isotopes indicated

Correlation measurements

Search for weak currents beyond the Standard Model



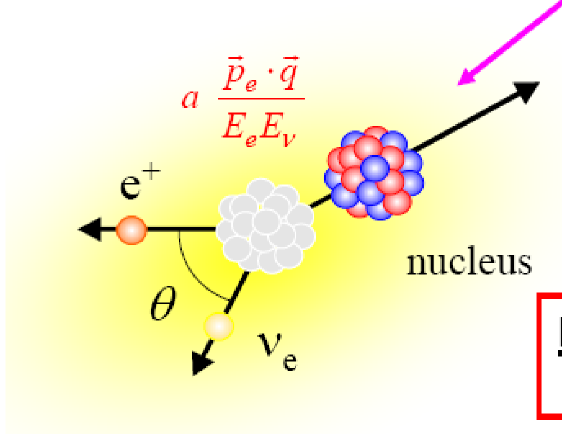
decay rate for **beta decay**
of **(un)polarized nuclei :**

Precision experiments with long beam times

- **data taking (statistics)**
- **instrument calibration (systematic errors)**

$$\omega(E,\,\Omega,\,\ldots)\;\propto\;\xi\left\{1\;+\;a\,\frac{\vec{p}_e\cdot\vec{q}}{E_eE_\nu}\;+\;b\,\frac{\gamma m_e}{E_e}\;+\;A\,\frac{\vec{J}}{J}\cdot\frac{\vec{p}_e}{E_e}\;+R\,\vec{\sigma}\cdot\frac{\vec{J}}{J}\times\frac{\vec{p}_e}{E_e}+\ldots\right\}$$

β-ν correlation | **Fierz interference term (b ≡ 0 in standard model)** | **β-asymmetry** | **R-correlation**



$$\tilde{X}=\frac{X}{1\;+\;b\,\frac{\gamma m_e}{E_e}}\qquad (X\;=\;a,\;A,\;\ldots)$$

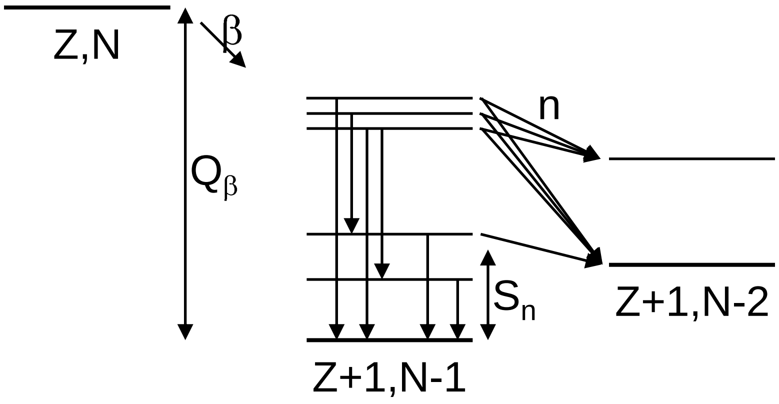
$$\gamma=\sqrt{1-(\alpha Z)^2}$$

Note: ***a***, ***b***, ***A***, ***R***, … depend on the coupling strengths for the different possible weak interaction types (i.e **A**, **V**, **S**, **T**)

Case II: Nuclear Structure

Ex. β-decay spectroscopy:

interest in small β-decay branches:



- Decay rate $\lambda \sim f \times |M|^2$
  - ✓ branching ratio = λ/λ_{tot}
- Beta-decay f-factor ~ $(Q-E)^5$
  - ✓ transitions with large strength to high E
- Allowed / first forbidden / …

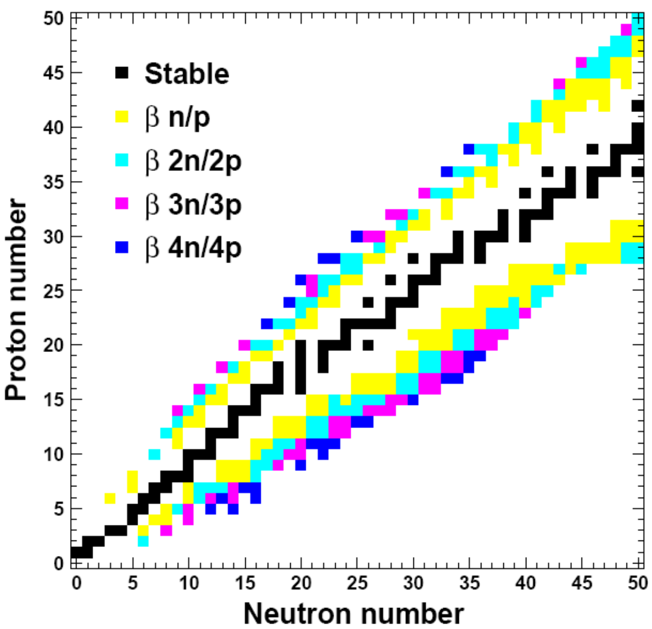
Required equipment:

- Implant in catcher foil / detector – trap
- Polarized beams? E.g., ^{11}Li (Hirayama et al., PL B611 (2005) 239)
- Detectors for β, γ, charged particles, n

Possible subjects:

- Beta-delayed (multi-)particle emission
- Decay of halo nuclei
- Cluster studies

Possible subjects for nuclear structure

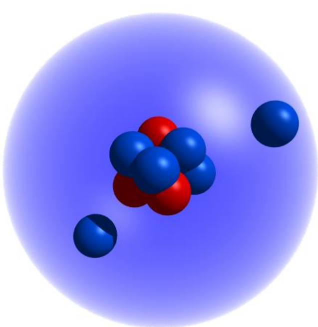


1. (Multi-)particle emission

- β n/p emission: study of p/γ competition
- β 2p : only data for ^{31}Ar
- β 2n : very limited information ^{11}Li, ^{19}C, $^{30-34}$Na, ^{52}K
- β d/t emission: ^{6}He (β,d); ^{8}He (β,t)
- New branches
  - ^{8}He (β,d); ^{11}Li (β,pn)
  - βt ^{29,30,32}Ne, ^{32,33,34}Na; βd ^{32}Ne, ^{34}Na

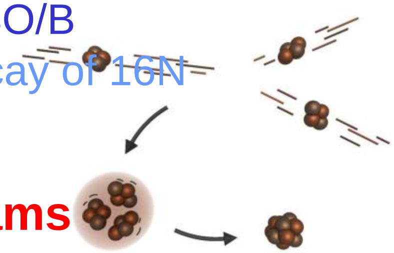
2. Decay of 'Halo' nuclei

- Decay into continuum
- Clustering



3. Other cluster studies

- 12C – 3 α's: decay of 12N/B
  - 13N/C – add nucleon: decay of 13O/B
- 16O – 4 α's / 12C+α: decay of 16N

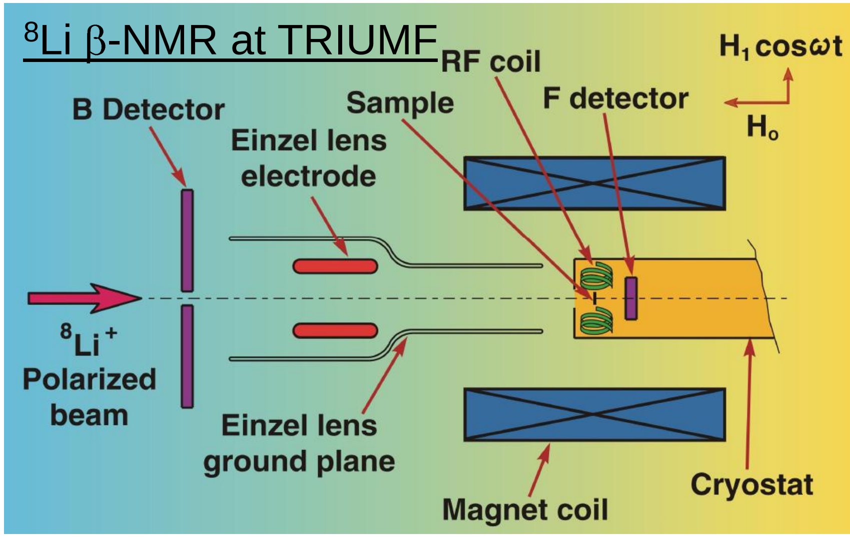


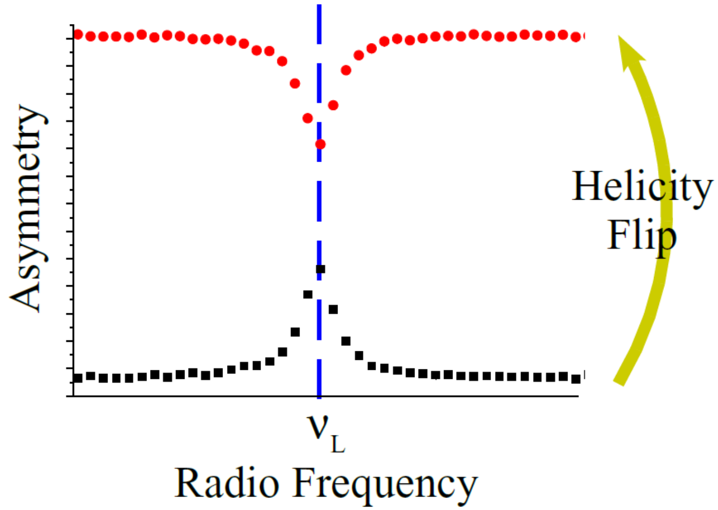
Hunt for very weak signals

- **Selective, high-intensity beams**
- **Long beam times**

Case III: Solid-state physics (^{8}Li β-NMR)

- produce polarized ^{8}Li
  - circularly polarized laser light
  - asymmetry in β-decay of ^{8}Li
- Implant ^{8}Li in surface
  - destroy asymmetry by sending in NMR signal
- Frequency and line shape tells about interaction between solid and ^{8}Li





What happens near an interface?
• We go from 3D to 2D system
• Changes in magnetic, electronic and structural properties.

Questions:
How/why do the properties change?
On what scale ?

Motivation:
Better understanding of *both bulk and interface*
Application in devices.

(Open) issues and future

•ISOL@MYRRHA is an integral part of the MYRRHA project

•Workplan – roadmap (close contact between possible users and the MYRRHA team):

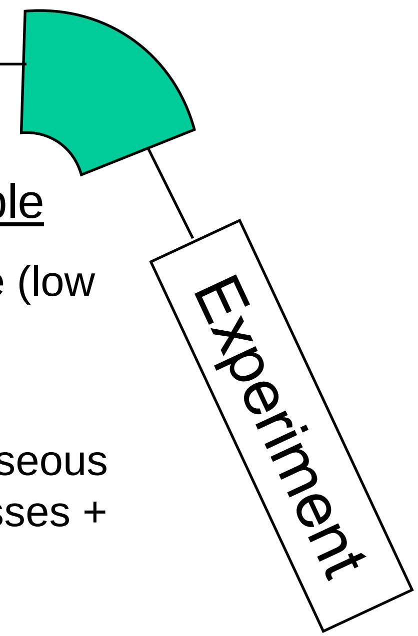
- ➢ Approval and initial funding of the MYRRHA project
- ➢ Preliminary report
  - physics cases : look what will (is planned to) be done by 2020.
  - technical specifications from the users point of view
  - budgetplan/estimate
- ➢ Establishing a users group (including users outside of nuclear physics)
- ➢ Gathering ISOL expertise at SCK•CEN
- ➢ Operational model
- ➢ Time line

•Further applications for the full 2.5 mA beam (neutron factory)?

ISOL@MYRRHA

MYRRHA accelerator → 2.5 mA → MYRRHA spallation source and reactor

100 μA → ISOL target — 1^+ ion source — Mass separator



MYRRHA accelerator

- Proton beam
- 600 MeV (upgradeable to 1 GeV)
- 2.5 mA
- High reliability: less than 5 beam trips (>1 s) per 3 months

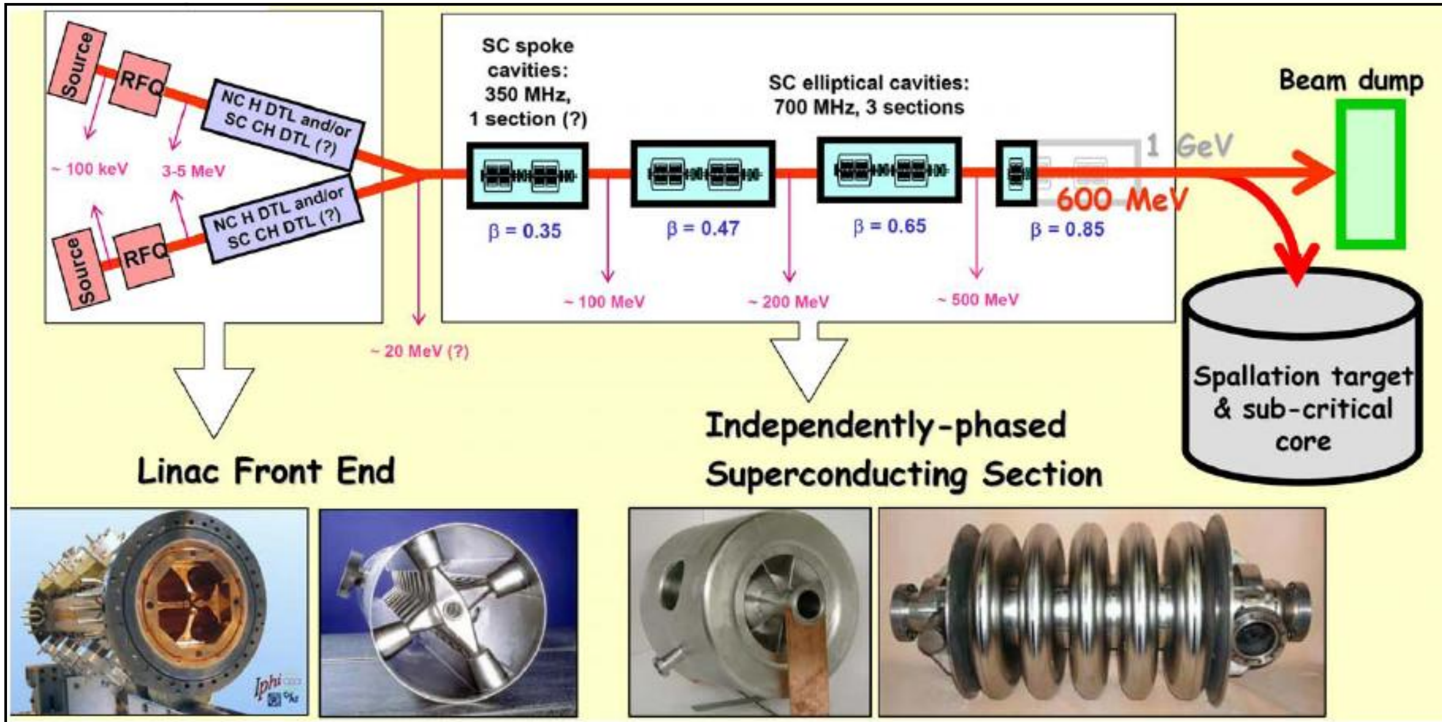
ISOL target — Ruggedized

- SiC/C (Z=14)
- TiC/C (Z=22)
- Nb (Z=41)
- La (Z=57)
- Ta (Z=73)
- UC/C (Z=92)

1^+ ion source — Selective + Reliable

- Surface ion source (low IP: (earth) alkali)
- Cold transfer tube coupled to ECR (gaseous elements: noble gasses + C,N,O,…)
- Resonant Laser Ionization

The MYRRHA linear accelerator

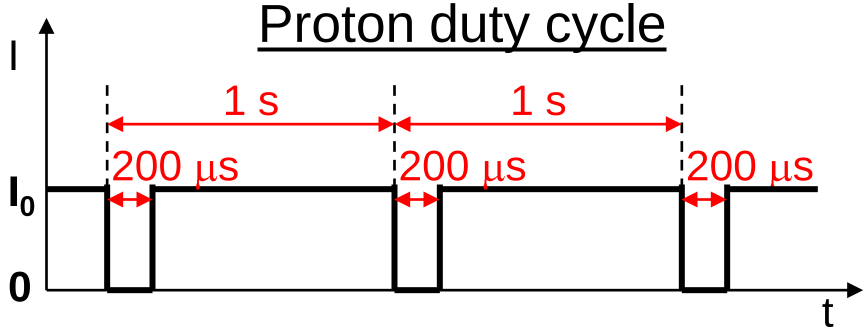


Picture taken from Alex C. Mueller, BriX workshop 2008

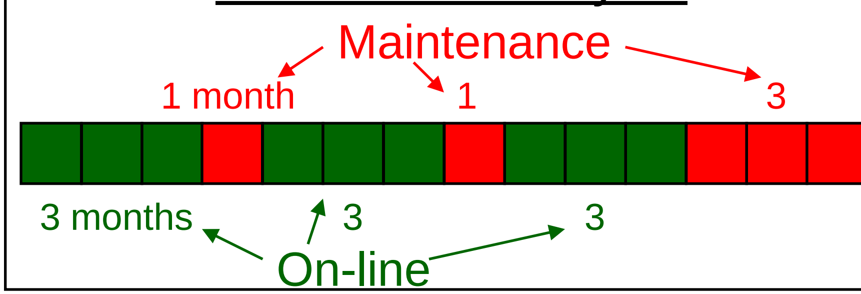
Specifications

- Proton beam
- 600 MeV (upgradeable to 1 GeV)
- 2.5 mA
- High reliability: less than 5 beam trips (>1 s) per 3 months

Proton duty cycle



The MYRRHA cycle



Ruggedized targets and sustainable ion sources

Typical ISOLDE beam power of 2 kW can be managed adequately.
ISOL@MYRRHA beam power management of 60 kW becomes challenging!

Use ruggedized targets like:

- SiC/C (Z=14), TiC/C (Z=22) ← Powder targets
- Nb (Z=41), Ta (Z=73) ← Metal foil targets
- UC/C (Z=92) ← Powder target

State-of-the-art ruggedized targets:

- TRIUMF, Vancouver (Canada)
  - ✓ 500 MeV, 100 μA proton beam
- EURISOL design study
  - ✓ 1 GeV, 100 μA proton beam

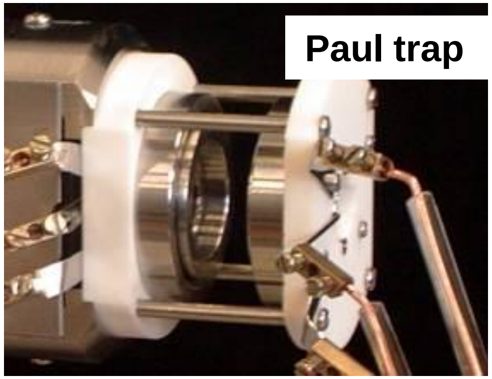
ISOL@MYRRHA: intense beams + long beam times

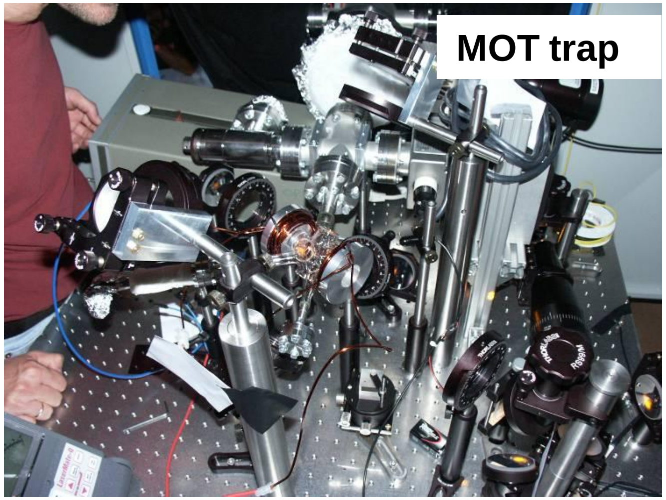
Use sustainable ion sources like:	For ionization of:
Surface ion source (W, Re)	Alkali elements (low ionization potential)
Cold transfer tube with ECR source	Gaseous elements (noble gases, C, N, O)
Resonant Laser Ion Source	~80% of the elements with high selectivity

Correlation measurements

- β-ν **momentum correlation**
  - ➢measure nuclear recoil
  - ➢use ion/MOT traps
  - ➢$\beta\nu$-correlation from Doppler-shift of β-delayed γ-rays

    Doppler shift from
    precise measurement of
    γ-ray energy
    with a
    crystal spectrometer
- **β-asymmetry**
  - ➢β emission direction from polarised nuclei
- **R-correlation**
  - ➢combination of β particle spin polarisation and nuclear polarisation





Precision experiments with long beam times
- data taking (statistics)
- instrument calibration (systematic errors)